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THE EMITTANCE OF CERAMICS AND GRAPHITES

DEFENSE METALS INFORMATION CENTER
BATTELLE MEMORIAL INSTITUTE
COLUMBUS 1, OHIO

THE EMITTANCE OF CERAMICS AND GRAPHITES

W. D. Wood, H. W. Deem, and C. F. Lucks*

INTRODUCTION

There has been, for some years, a considerable interest in data on the thermal properties of materials. Many of these data are reported in an excellent manner by Armour Research Foundation in WADC TR-58-476, Volumes I through IV. Data available through 1957 are included.

Recently there has been an increased and particular interest in the radiant heat transfer and thermal-radiation properties. The fundamentals and nomenclature of radiant heat transfer are often not familiar to those who now find themselves concerned with it.

The Defense Metals Information Center has prepared a series of memorandums in the general field of radiant heat transfer to make this information and the data on thermal-radiation properties more readily available. Each memorandum is being directed toward providing information in a particular area of interest. Included are basic fundamentals, definitions and methods used in measuring the radiant-heat-transfer properties of materials, as well as literature values of these properties for selected materials. This series of memorandums ultimately will be assembled into a report for those with a broad interest in radiant heat transfer.

This present memorandum is the last of the series and is a compilation of original test data on emittance, reflectance, and transmittance of ceramics and graphites. Although these materials are on the borderline of the DMIC scope, the data were uncovered during the general search and are included to complete the record. The data were taken from the literature published during the period 1940-1959, inclusive, and as much of the 1960 literature as could be obtained. The following sources were searched: Chemical Abstracts, Ceramic Abstracts, Metallurgical Abstracts, Nuclear Science Abstracts, and the files of the Defense Metals Information Center (DMIC). The authors have attempted to evaluate these scurces of data according to the apparent thoroughness of methods and techniques as described by the various investigators. In many cases the descriptions in the literature are a summary of methods and results, and a complete evaluation is impossible. With these considerations in mind the authors have shown curves which, in their estimation, indicate the most probable values for the various conditions and materials.

^{*}Principal Physicist, Assistant Chief, and Chief, respectively, Instrumentation Division, Battelle Memorial Institute.

METHOD OF PRESENTATION OF DATA

The data have been separated according to material and to the type of measurement, whether spectral or total.

In previous publications of this series, emittance data are given as the complement of the reflectance, which assumes a sample opaque to the radiation concerned in each case. Many of the ceramic materials transmit considerable amounts of incident radiation and must be relatively thick to be effectively opaque. The data in this memorandum are, therefore, given only in the units measured by the investigators, since for most cases the emittance must be considered as the complement of the sum of the reflectance and the transmittance.

All data have been plotted with each reference shown by different symbols. The reference-information sheet accompanying each graph gives the names of the investigators and the number of the reference from which the data were obtained. Notations of composition and surface condition of the sample tested, and a brief notation on the methods and conditions of measurement, are given when available.

The curves drawn by the authors have been prepared with special emphasis on the extremes found in the literature for the polished and oxidized conditions. The information for other surface conditions is contained in the accompanying reference-information sheet.

Further information concerning methods used may be found in the particular reference given or in DMIC Memorandum No. 78, "Methods of Measuring Emittance".

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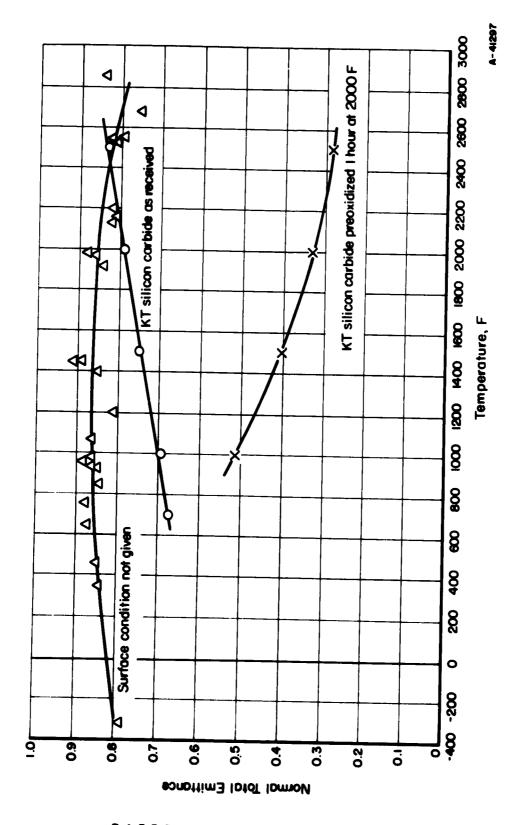
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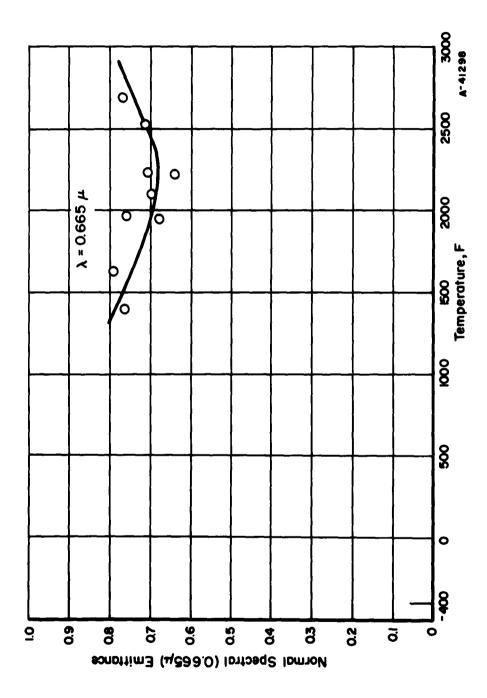
EMITTANCE DATA



NORMAL TOTAL EMITTANCE OF SILICON CARBIDE

NORMAL TOTAL EMITTANCE OF SILICON CARBIDE -- REFERENCE INFORMATION

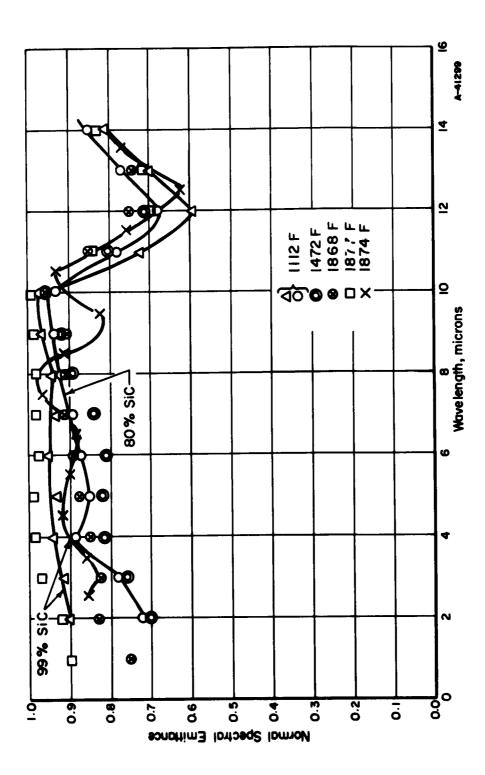
Reference	Investigator	Symbo 1	Composition and Surface Condition	Test Method	Remarks
	Anthony and Pearl	ox	KT Silicon carbide As received Pre-oxidized in air l hour at 2000 F	Normal total emittance. Induction-heated specimen. Comparison blackbody. Thermopile detector. Temperatures measured with thermocouples.	Measured in purge of dry helium gas. Data taken from table.
8	Olson and Morris	٩	Silicon carbide Surface condition not given	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.



NORMAL SPECTRAL EMITTANCE OF SILICON CARBIDE

NORMAL SPECTRAL EMITTANCE OF SILICON CARBIDE.-REFERENCE INFORMATION

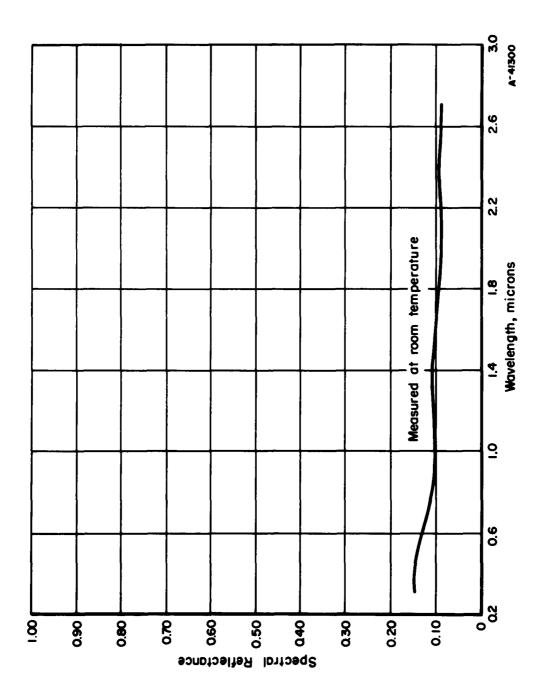
Reference Investigator Symbol Surface Condition R 2 Olson and Morris O Silicon carbide Surface condition not given		
0	Composition and Surface Condition Test Method	Remarks
1 N	Normal spectral emittance. Furnace-heated specimen. Comparison blackbody. Commercial detector and filter system for peak response at 0.6654. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. $(\lambda = 0.665 \mu)$



NORMAL SPECTRAL EMITTANCE OF SILICON CARBIDE

NORMAL SPECTRAL EMITTANCE OF SILICON CARBIDE - REFERENCE INFORMATION

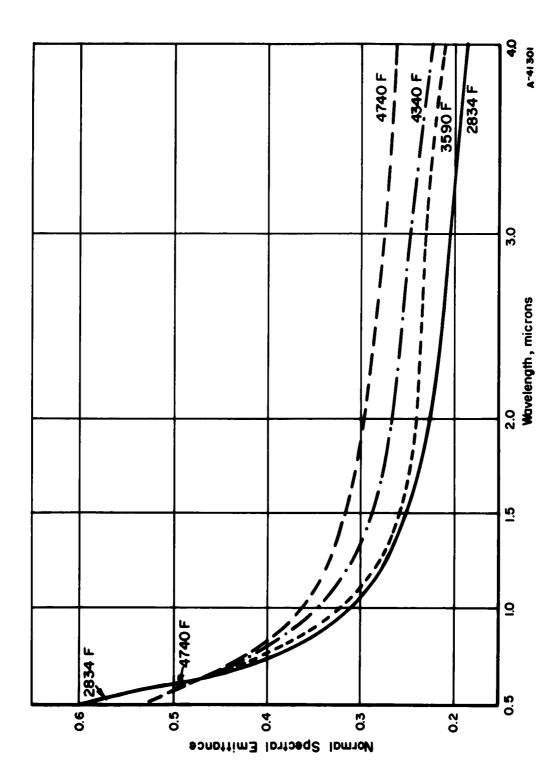
Reference	Investigator	Symbo1	Composition and Surface Condition	Test Method	Remarks
ო	Blau, Marsh, Martin, Jasperse, and Chaffee		Silicon carbide Diamond wheel finish as supplied by manufacturer	Normal spectral emittance. Specimen mounted in wall of cylindrical Globar (SiC) heater.	Measured in air. Data taken from curves. (Curves are drawn
			Crystolon R (Norton) 99% + pure	Comparison blackbody hole also in heater	through the 1112 F points only.
		٥	Measured at 1112 F	Temperatures measured	
		0	Measured at 1877 F RC4237 (Norton) 80% pure	<pre>with thermocouples. Monochromator and thermocouple detector.</pre>	
		0	Measured at 1112 F		
		•	Measured at 1472 F		
		•	Measured at 1868 F		
च	Blau, Chaffee, Jasperse, and Martin	×	99 per cent silicon carbide (Norton Crystalon R)	Normal spectral emittance. Induction-heated specimen. Comparison blackbody.	Measured in 90% argon, 10% hydrogen atmos-
			Flat smooth surface from diamond wheel cutting.	Monochromator and thermocouple detector. Temperatures measured with micro-optical	Data taken from curve.
			The minima at about 9 and 12 microns are attributed to a thin SiOz surface film.	pyrometer.	



SPECTRAL REFLECTANCE OF SILICON CARBIDE

SPECTRAL REFLECTANCE OF SILICON CARBIDE-REFERENCE INFORMATION

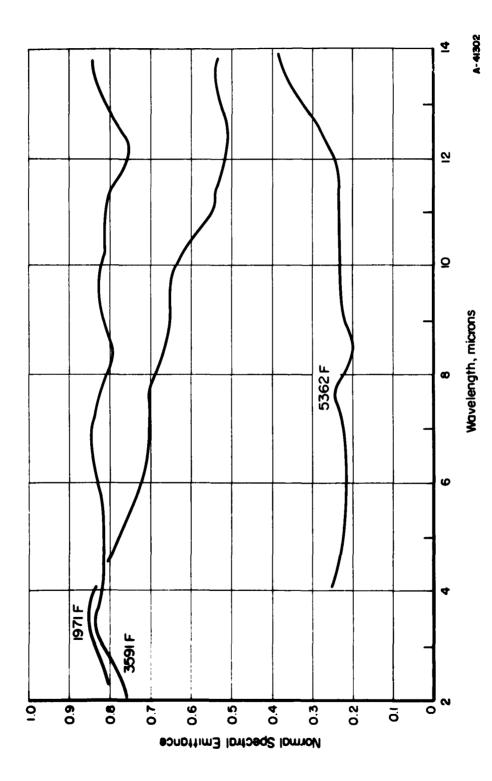
R Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
~ N E M	Olson and Morris		Silicon carbide, purity and surface condition	Spectral reflectance. Incident radiation	Measured in air at room temperature.
0 R				to specimen surface.	Curves.
IAL				Integrating sphere reflectometer.	
ı				Monochromator and lead sulphide detector.	
N S T				Normal (9 degrees)	
1 T				Diffuse reflection.	



NORMAL SPECTRAL EMITTANCE OF TANTALUM CARBIDE (0.5 TO 4 MICRONS)

NORMAL SPECTRAL EMITTANCE OF TANTALUM CARBIDE (0.5 TO 4 MICRONS) -- REFERENCE INFORMATION

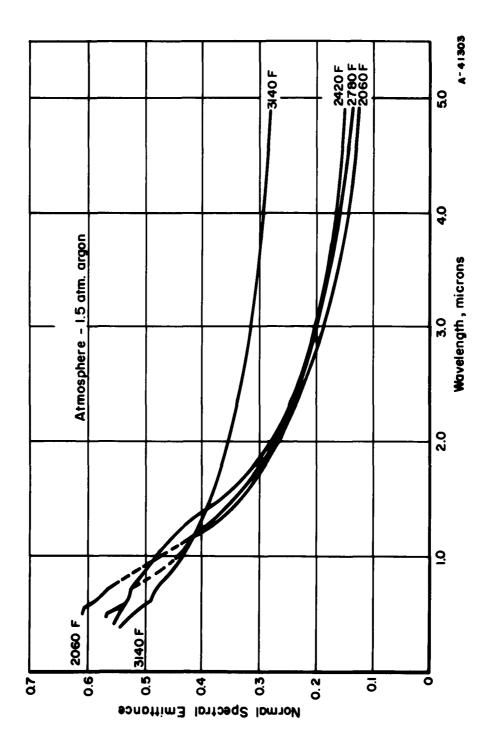
R Reference	Investigator	Symbo 1	Composition and Surface Condition	Test Method	Remarks
φ MEMORIAL	Riethof		Tantalum carbide Composition or surface condition not given Measured at 2834, 3590, 4340, and 4740 F	Normal spectral emittance. Induction-heated specimen. Blackbody hole in specimen surface. Thermocouple detector. Monochromator. Temperatures measured with optical pyrometer.	Measured in argon. Data taken from curves.



NORMAL SPECTRAL EMITTANCE OF TANTALUM CARBIDE (2 TO 14 MICRONS)

NORMAL SPECTRAL EMITTANCE OF TANTALUM CARBIDE (2 TO 14 MICRONS) -- REFERENCE INFORMATION

r Reference	Investigator	Symbo1	Composition and Surface Condition	Test Method	Remarks
M E M O R I A L I	Blau, Chaffee, Jasperse, and Martin	•	Tantalum carbide Purity not given Surface flat and smooth but not polished (Note: Surface analysis after 3234 K (5362 F) run showed thin tantalum oxide film)	Normal spectral emittance. Induction-heated specimen. Comparison blackbody. Monochromator and thermocouple detector. Temperatures measured with optical pyrometer.	Measured in 90% argon 10% hydrogen atmos- phere. Data taken from curves.

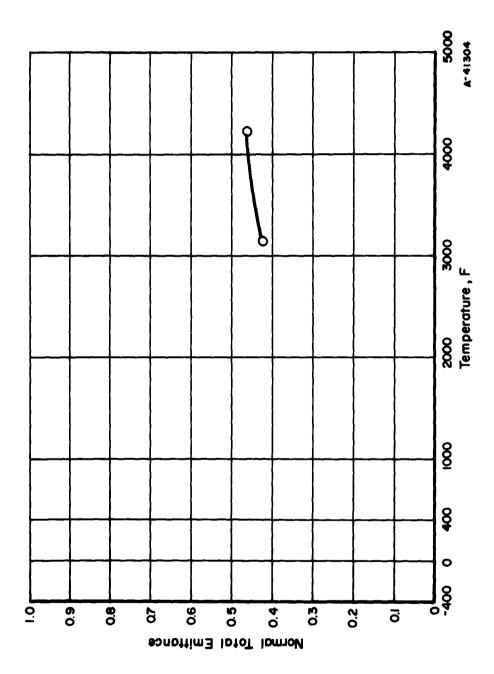


NORMAL SPECTRAL EMITTANCE OF TUNGSTEN CARBIDE

NORMAL SPECTRAL EMITTANCE OF TUNGSTEN CARBIDE -- REFERENCE INFORMATION

Composition and Surface Condition Test Method Remarks	Tungsten carbide (WC) Surface condition or purity not given purity not formation from WC to W2C at 3140 F Measured at 2060, 2780, Surface condition or Induction—heated specimen. atmosphere of atmosphere of argon. argon. Data taken from Thermocouple detector. Curves. Monochromator. Temperatures measured with optical pyrometer.
Symbol	-
Investigator	Coffman, Coulson, and Kibler
Reference	ιn O

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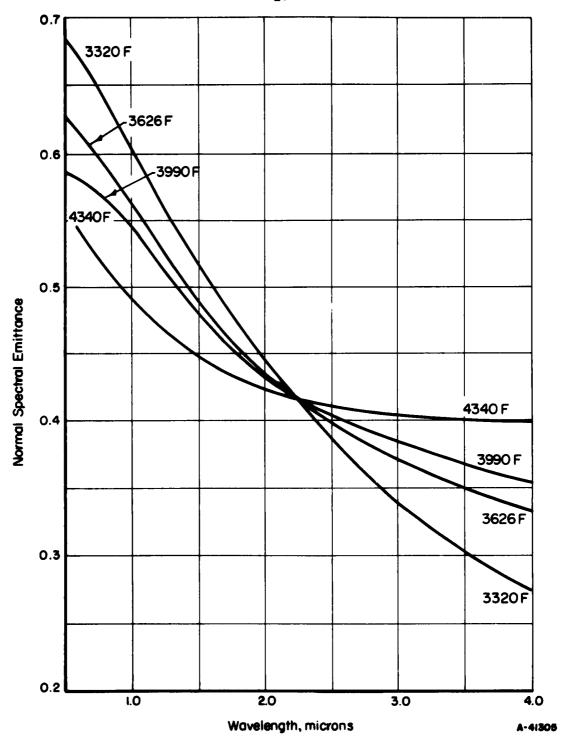
NORMAL TOTAL EMITTANCE OF ZIRCONIUM CARBIDE

NORMAL TOTAL EMITTANCE OF ZIRCONIUM CARBIDE.--REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
ν	Coffman, Coulson, and Kibler	0	Formed into "toadstool" shaped specimen Composition and surface condition not given	Normal total emittance. Induction-heated specimen. Comparison blackbody. Temperatures measured with optical pyrometer.	Measured in 1.5 atmosphere of dry, pure, argon. Data taken from curve.

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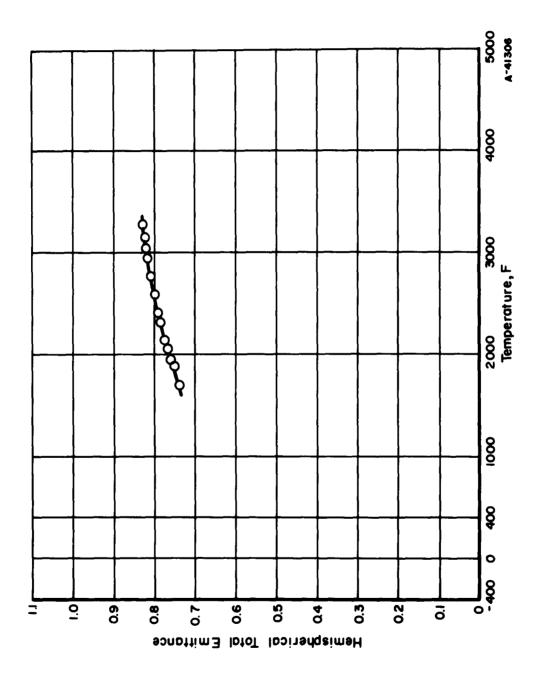


NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM CARBIDE

NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM CARBIDE--REFERENCE INFORMATION

	NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM CARBIDEREFERENCE INFORMATION				
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
ø	Riethof		Zirconium carbide Composition or surface condition not given Measured at 3320, 3626, 3990, and 4340 F	Normal spectral emittance. Induction-heated specimen. Blackbody hole in specimen surface. Thermocouple detector. Monochromator. Temperatures measured with optical pyrometer.	Measured in argon. Data taken from curves.

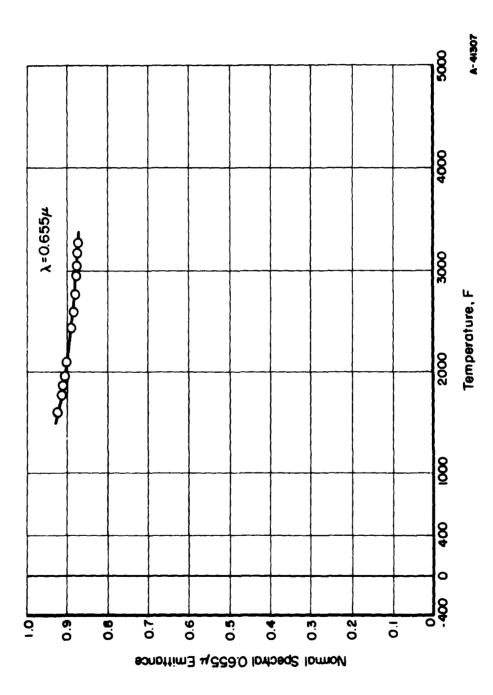
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HEMISPHERICAL TOTAL EMITTANCE OF ACHESON GRAPHITE

HEMISPHERICAL TOTAL EMITTANCE OF ACHESON GRAPHITE.-REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
MEMORIAL INSTI	Jain and Krishnan	0	Acheson graphite Sample held at 2000 K for 1 hour in vacuum, until emittance became steady and reproducible	Hemispherical total emittance. Hole-in-tube method. Correction of inside blackbody temperature to surface temperature made using known thermal conductivity and wall thickness. Blackbody temperature measured with optical	Measured in vacuum. Data taken from curves.
TUTE					

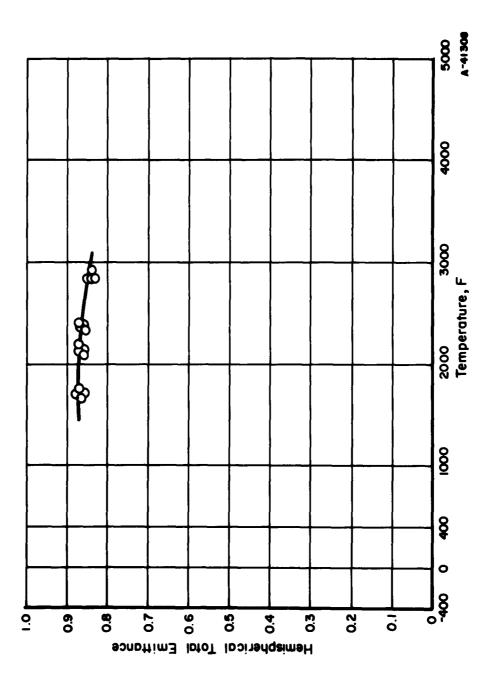


NORMAL SPECTRAL EMITTANCE OF ACHESON GRAPHITE

NORMAL SPECTRAL EMITTANCE OF ACHESON GRAPHITE.--REFERENCE INFORMATION

		-29-	
Remarks	7	weasured in vacuum. Data taken from curves. $(\gamma = 0.665 \mu)$	
Test Method		Normal spectral emittance. Hole-in-tube method. Temperatures measured with optical pyrometer.	
Composition and	Surface Condition	Acheson graphite Specimen held at 2000 K for 1 hour in vacuum until emittance became steady and reproducible	
	Symbol	0	
	Investigator	Jain and Krishnan	
	Reference	•	

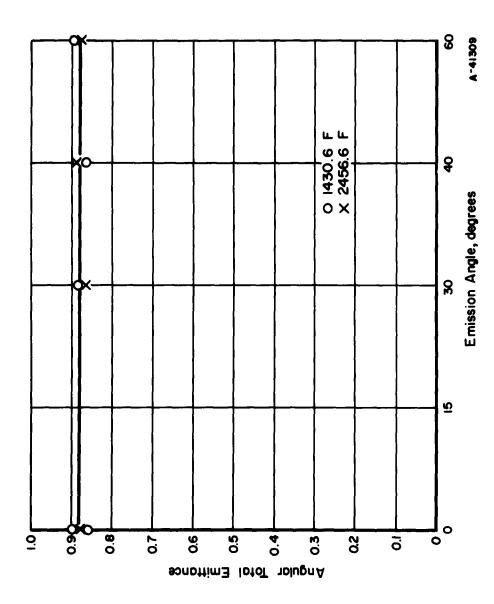
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HEMISPHERICAL TOTAL EMITTANCE OF ATJ GRAPHITE

HEMISPHERICAL TOTAL EMITTANCE OF AIJ GRAPHITE -- REFERENCE INFORMATION

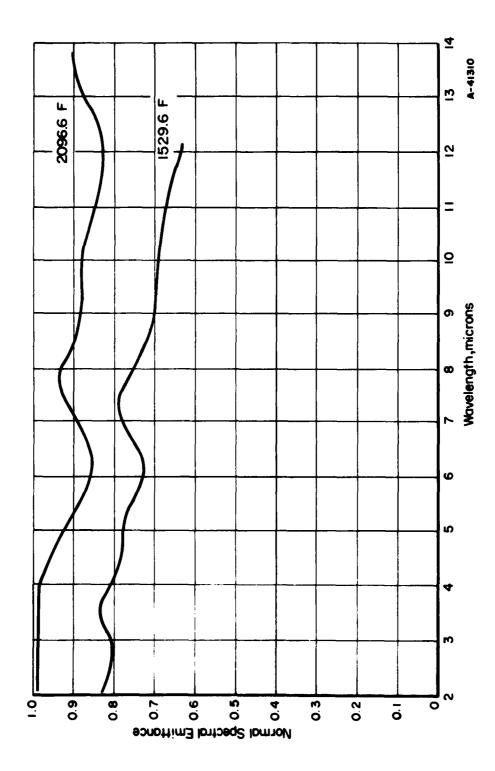
Reference	Investigator	Symbol	Composition and Surface Condition	Took Mother	
				poliner rest	Kemarks
4	Blau, Chaffee, Jasperse, and Martin	0	AIJ graphite Surface condition not given	Normal total emittance. (Hemispherical emittance equals normal emittance for this specimen.) Induction-heated specimen. Monochromator with prism replaced by plane mirror. Thermocouple detector. Blackbody hole drilled in specimen surface. Temperatures measured	Measured in 90% argon - 10% hydrogen atmosphere. Data taken from curves.
				With mitto-optical pyrometer.	



TOTAL EMITTANCE VERSUS EMISSION ANGLE OF ATJ GRAPHITE

TOTAL EMITTANCE VERSUS EMISSION ANGLE OF ATJ GRAPHITE -- REFERENCE INFORMATION

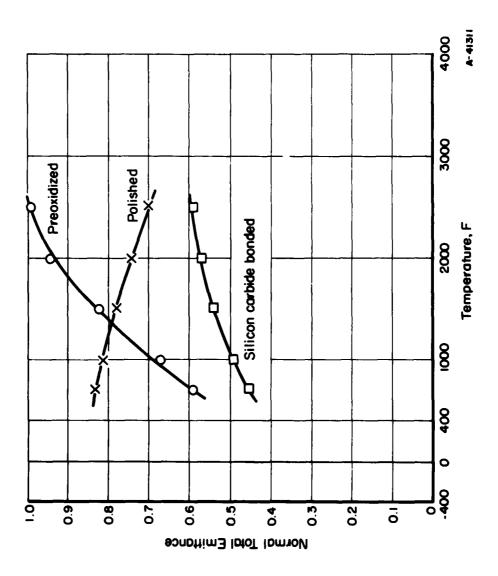
r Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
4	Blau, Chaffee,		ATJ graphite	Total emittance measured	Measured in 90%
	Jasperse, and Martin		Surface smooth and flat, but not polished.	normally and at 30, 45, and 60 degrees from the	argon - 10% hydrogen atmos-
.		0	Measured at 1431 F	normal. Induction—heated	phere. Data taken from
•		×	Measured at 2457 F	specimen.	curves.
		•		Monochromator with	
•				prism replaced by	Normal emittance
•				plane mirror.	equals hemispher-
•				Thermocouple detector.	ical emittance
				Blackbody hole drilled	for this specimen.
				in specimen surface.	
				Temperatures measured	
•				with micro-optical	
7				pyrometer.	
1					



NORMAL SPECTRAL EMITTANCE OF ATJ GRAPHITE

NORMAL SPECTRAL EMITTANCE OF ATJ GRAPHITE.--REFERENCE INFORMATION

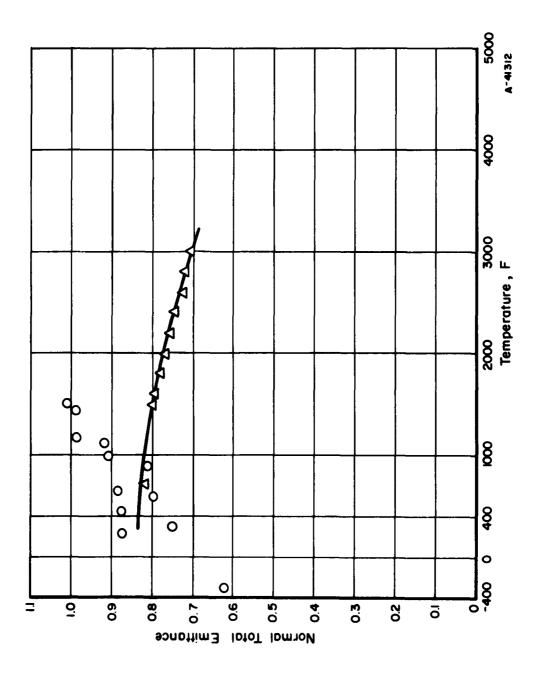
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
4	Blau, Chaffee, Jasperse, and Martin		ATJ graphite Surface smooth and flat but not polished	Normal spectral emittance. Induction-heated specimen. Monochromator and thermo- couple detector. Blackbody hole drilled in specimen surface. Temperatures measured with micro-optical pyrometer.	Measured in 90% argon - 10% hydrogen atmos-phere. Data taken from curves.



NORMAL TOTAL EMITTANCE OF ELECTRODE GRAPHITE

NORMAL TOTAL EMITTANCE OF ELECTRODE GRAPHITE--REFERENCE INFORMATION

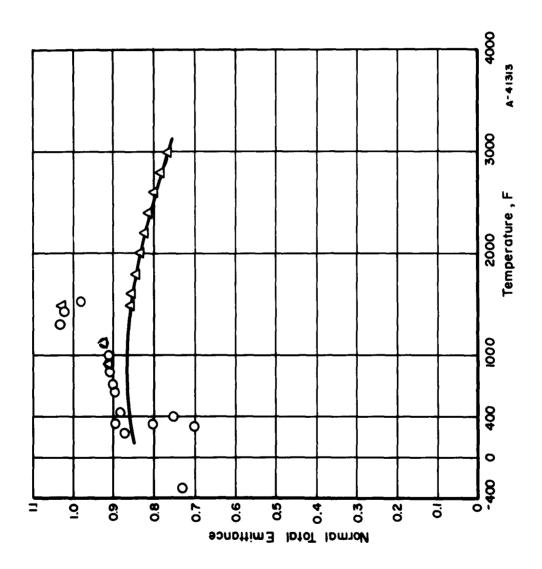
E			Composition and		-
Reference	Investigator	Symbol	Surface Condition	Test Method	Kemarks
	Anthony and Pearl		Electrode graphite	Normal total emittance.	Measured in purge
• •		0	Preoxidized	induction-neated specimen.	Data taken from
R 1		×	Polished	Comparison blackbody.	table.
AL		0	Silicon carbide bonded	Inermopile detector. Temperatures measured	
				with thermocouples.	



NORMAL TOTAL EMITTANCE OF GBE GRAPHITE

NORMAL TOTAL EMITTANCE OF GBE GRAPHITE-REFERENCE INFORMATION

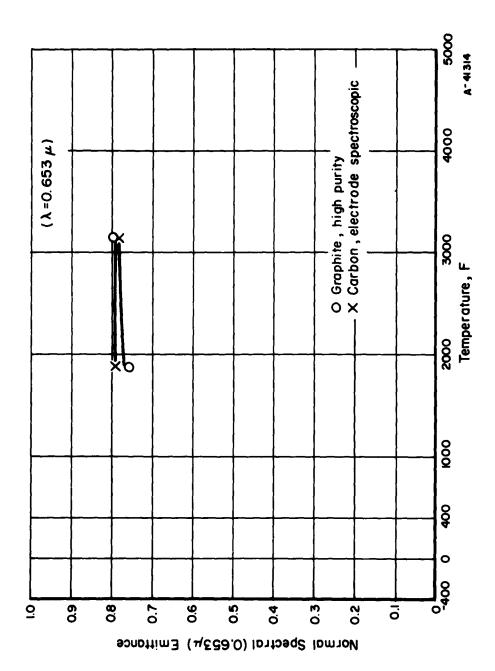
m r Reference	Investigator	Symbo1	Composition and Surface Condition	Test Method	Remarks
	Olson and Morris	0	National GBE graphite Surface condition not given	Normal total emittance. Resistance-heated strip specimen. Comparison blackbody. Temperatures measured with thermocouples. Thermistor detector.	Measured in vacuum. Data taken from curves.
- 1 A L	Betz, Olson, Schurin, and Morris	٥	Same as above	Same as above.	Same as above.



NORMAL TOTAL EMITTANCE OF TYPE GBH GRAPHITE

NORMAL TOTAL EMITTANCE OF TYPE GBH GRAPHITE.-REFERENCE INFORMATION

T T E	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
	Olson and Morris	0	National GBH graphite Surface condition not given	Normal total emittance. Resistance-heated strip specimen.	Measured in vacuum. Data taken from curves.
4 E M O			Note: Changed with cycling	Thermistor detector. Temperatures measured with thermocouples.	,-
r I A L	Betz, Olson, Schurin, and Morris	٥	Surface condition not given	Same as above.	Measured in vacuum. Data taken from table.
					!

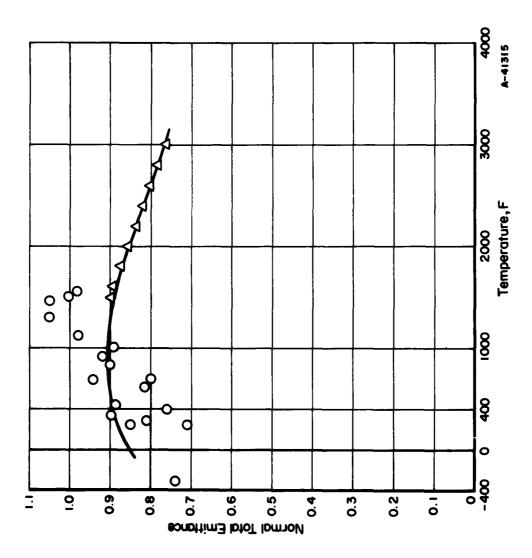


NORMAL SPECTRAL EMITTANCE OF GRAPHITE AND CARBON

NORMAL SPECTRAL EMITTANCE OF GRAPHITE AND CARBON --- REFERENCE INFORMATION

Doforonce	Investinator	Sumbol	Composition and	Toc+ Mothod	Domosely
	to of the sailt	c ympor		TORE MCCIO	Vellatiks
01	Thorn and Simpson	0	High-purity, medium-	Normal spectral emittance.	Measured in
•			density graphite	Modified hole-in-tube	vacuum.
				method.	Data taken from
_		×	Spectroscopic electrode		curves.
			carbon	Temperatures measured	
_				with calibrated	(N= 0.653 x)
•			Surface condition,	optical pyrometer.	
			polished and then		
			heated to 1800 K in		
•			vacuum for 3 hours		
•					

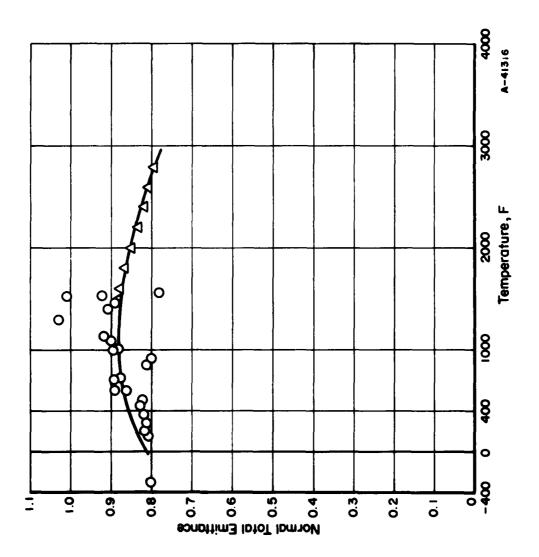
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NORMAL TOTAL EMITTANCE OF TYPE 3474D GRAPHITE

NORMAL TOTAL EMITTANCE OF TYPE 3474D GRAPHITE -- REFERENCE INFORMATION

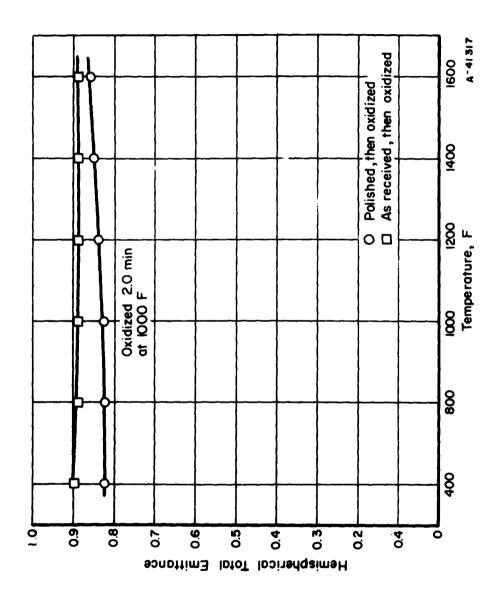
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
ω	Olson and Morris	0	Speer 3474D graphite Surface condition not given	Normal total emittance. Resistance-heated strip specimen.	Measured in vacuum. Data taken from
			Note: Changed with cycling	Comparison blackbooy. Thermistor detector. Temperatures measured with thermocouples.	· car.
L	Betz, Olson, Schurin, and Morris	٥	Surface condition not given	Same as above.	Measured in vacuum. Data taken from table.



NORMAL TOTAL EMITTANCE OF TYPE 7087 GRAPHITE

NORMAL TOTAL EMITTANCE OF TYPE 7087 GRAPHITE -- REFERENCE INFORMATION

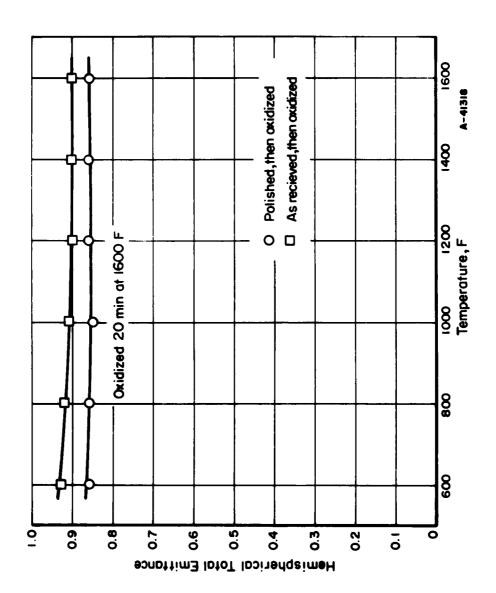
aniereirei L	Investigator	Symbol	Surface Condition	Test Method	Remarks
œ	Olson and Morris	0	Speer 7087 graphite Surface condition not given	Normal total emittance. Resistance-heated strip specimen.	Measured in vacuum. Data taken from curves.
			Note: Changed with cycling	Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	
^	Betz, Olson, Schurin, and Morris	٥	Surface condition not given	Same as above.	Measured in vacuum. Data taken from table.



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K150A Ni-Tic HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K150A NI-TIC HARD METAL--REFERENCE INFORMATION

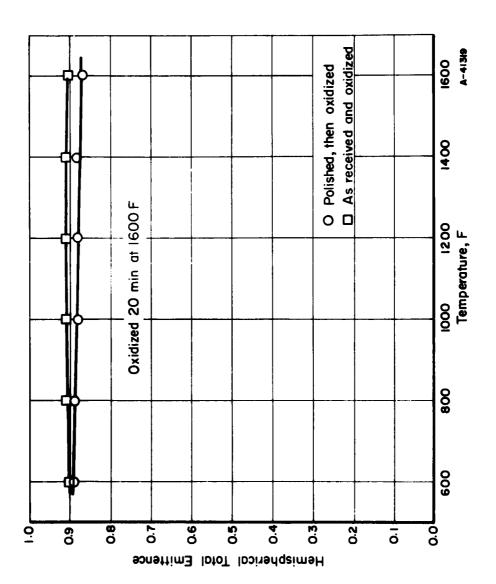
מבובובוב	Investigator	Symbol	Surface Condition	Test medical	
=	Wade and Casev		Composition: 10Ni,	Hemispherical total	Measured in air.
;			80Tic, 10CbC	emittance. (Total emittance	Data taken from curves.
		0	As received, then	measured normally	
		}	oxidized	and at various angles. Normal emittance	
		0	Polished: Hand lapped	equals hemispherical	
			with 3 micron and 1	emittance.)	
			micron diamond paste,	Thermopile total	
			then oxidized	ratiation detector.	
				Resistance-heated	
				specimen. Comparison	
				blackbody.	
				Temperatures measured	
				with thermocouples.	



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K151A Ni-Tic HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K151A Ni-Tic HARD METAL--REFERENCE INFORMATION

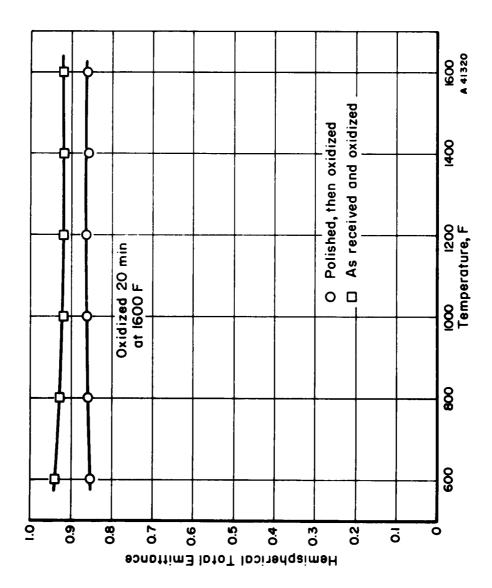
Reference	Investigator	Symbo1	Composition and Surface Condition	Test Method	Remarks
I MEMORIAL INSTI	Wade and Casey	ОО	Composition: 20Ni, 70TiC, 10CbC As received, then oxidized Polished; hand lapped with 3-micron and 1-micron diamond paste, then oxidized	Hemispherical total emittance. (Total emittance measured normally and at various angles. Normal emittance equals hemispherical emittance.) Thermopile total radiation detector. Resistance-heated specimen. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
. .	Composition:	20Ni, 70TiC, 10CbC	.c, 10CbC		



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K152B NI-TIC HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K152B Ni-Tic HARD METAL--REFERENCE INFORMATION

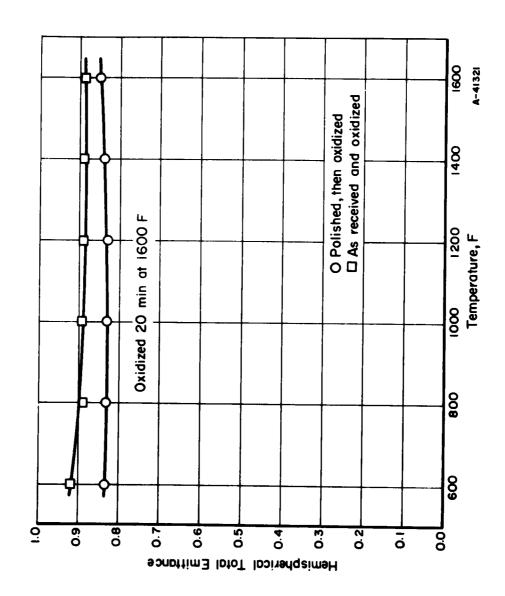
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
11	Wade and Casey	O	Composition: 30Ni, 65TiC, 5CbC As received, then oxidized Polished; hand lapped with 3-micron and 1-micron diamond paste, then oxidized	Hemispherical total emittance. (Total emittance measured normally and at various angles. Normal emittance equals hemispherical emittance.) Thermopile total radiation detector. Resistance—heated specimen. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K153B NI-TIC HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K153B Ni-Tic HARD METAL--REFERENCE INFORMATION

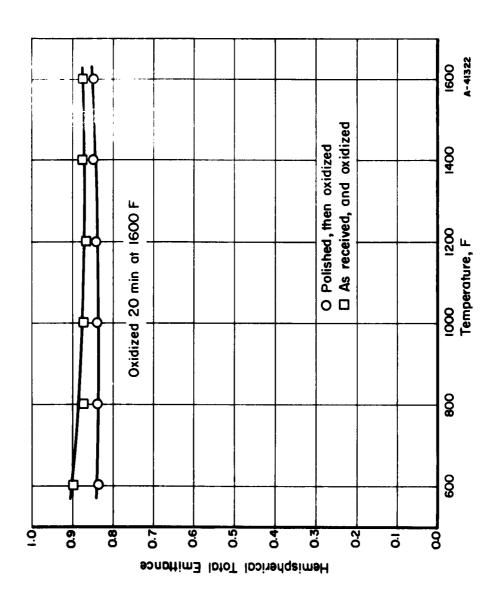
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
11	Wade and Casey		Composition: 40Ni, 54TiC, 6CbC	Hemispherical total emittance.	Measured in air. Data taken from
		((Total emittance	curves.
		-	As received, then oxidized 20 minutes at 1600 F	measured normally and at various	
		0	Polished; lapped with	angles. Normal	
			3-micron and 1-micron	emittance equals	
			diamond paste, then	hemispherical	
			oxidized 20 minutes at	<pre>emittance.)</pre>	
			1600 F	Thermopile total	
				radiation detector.	
				Resistance-heated	
				specimen.	
				Comparison blackbody.	
				Temperatures measured	
				with thermocouples.	



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K163B1 Ni-Tic HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K163B1 Ni-Tic HARD METAL--REFERENCE INFORMATION

r F Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
-	Wade and Casev		Composition: 33.3Ni, 54TiC,	Hemispherical total	Measured in air.
4			6.7Mo, 6CbC	emittance. (Total emittance	Data taken from curves.
			As received, then oxidized	measured normally	
			20 minutes at 1600 F	and at various	
		0	Polished; lapped with 3-	angles. Normal	
			micron and 1-micron	emittance equals	
			diamond paste, then	hemispherical	
			oxidized 20 minutes at	<pre>emittance.)</pre>	
			1600 F	Thermopile total	
				radiation detector.	
				Resistance-heated	
				specimen.	
				Comparison blackbody.	
				Temperatures measured	
				with thermocouples.	

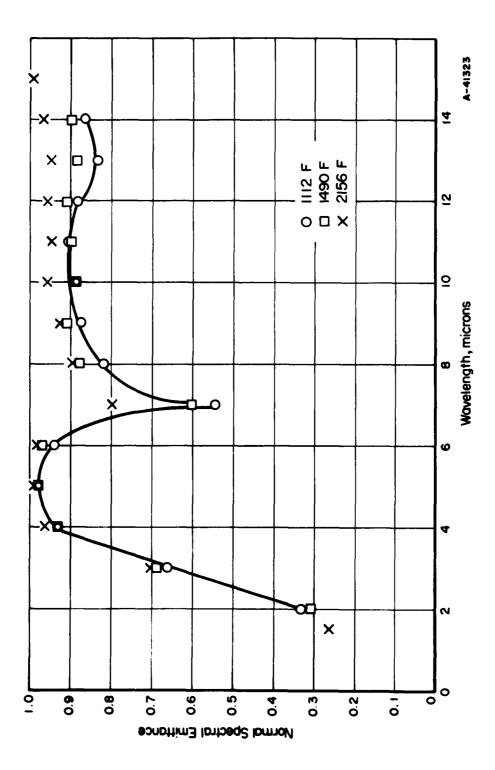


HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K184B Ni-Tic HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K184B Ni-Tic HARD METAL--REFERENCE INFORMATION

Reference	Investigator	Symbo 1	Composition and Surface Condition	Test Method	Remarks
==	Wade and Casey	_ O	Composition: 40Ni, 40TiC, 10CbC, 4Mo, 3Al, 3Cr As received, then oxidized 20 minutes at 1600 F Polished; lapped with 3-micron and 1-micron diamond paste, then oxidized 20 minutes at 1600 F	Hemispherical total emittance. (Total emittance measured normally and at various angles. Normal emittance equals hemispherical emittance.) Thermopile total radiation detector. Resistance—heated specimen. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.

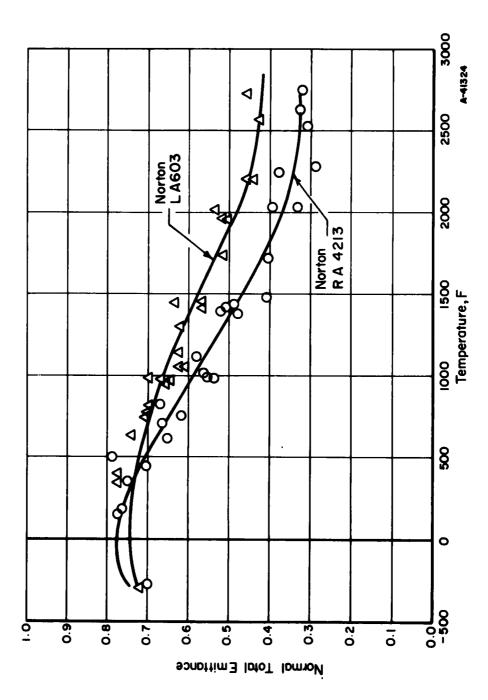
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NORMAL SPECTRAL EMITTANCE OF BORON NITRIDE

NORMAL SPECTRAL EMITTANCE OF BORON NITRIDE -- REFERENCE INFORMATION

			Composition and		Domarks	
Reference	Investigator	Symbol	Surface Condition	Test Method	Nelliat N. S.	
6	Blau, Marsh, Martin, Jasperse, and Chaffee		Boron nitride Purity and surface condition not given	Normal spectral emittance. Specimen mounted in wall of cylindrical	Measured in air. Data taken from curves.	
M 0 =		0 0	Measured at 1112 F Measured at 1490 F	Globar (SiC) heater. Comparison blackbody hole in heater wall.	(Curve drawn through 1112 F points only.)	-01-
. 1 🛦 1		×	Measured at 2156 F	Monochromator and thermocouple de-		
				Temperatures measured with thermocouples.		
N 1						11



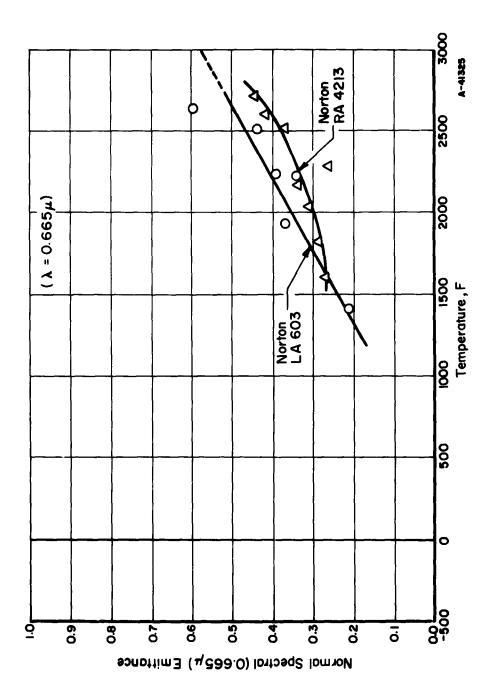
NORMAL TOTAL EMITTANCE OF ALUMINUM OXIDE

NORMAL TOTAL EMITTANCE OF ALUMINUM OXIDE -- REFERENCE INFORMATION

1		- 63-	- ;
Remarks	Measured in air. Data taken from	curves.	
Test Method	Normal total emittance. Furnace-heated specimen.	Comparison blackbody. Temperatures measured with thermocouples Thermistor detector.	
Composition and Surface Condition	Norton LA603 Aluminum oxide	Norton RA4213 Aluminum oxide	Surface condition not given
Symbol	۵	0	
Investigator	Olson and Morris		
Reference	8		

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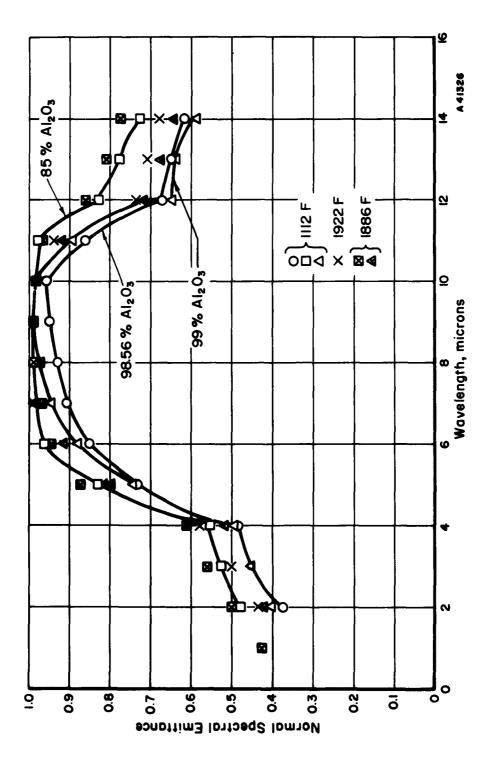
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NORMAL SPECTRAL EMITTANCE OF ALUMINUM OXIDE

NORMAL SPECTRAL EMITTANCE OF ALUMINUM OXIDE -- REFERENCE INFORMATION

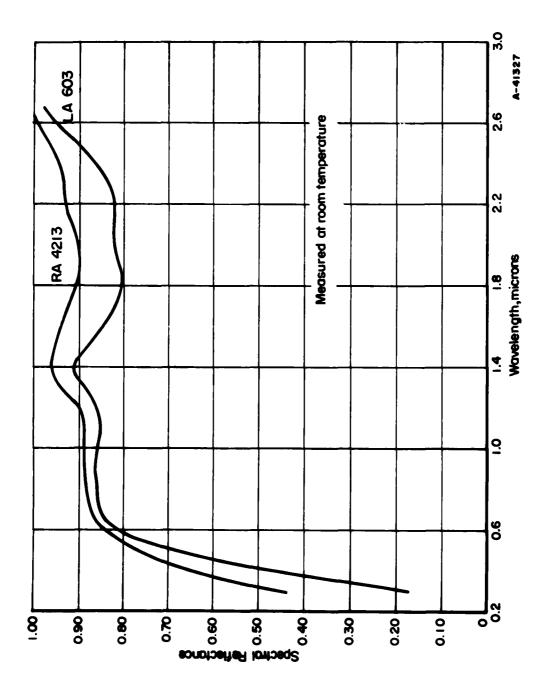
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
7	Olson and Morris	0	Norton LA603	Normal spectral emittance.	Measured in air.
			Aluminum oxide	Furnace-heated specimen.	Data taken from
		•		Comparison blackbody.	curves.
		٥	Norton RA4213	Commercial radiation	
			Aluminum oxide	detector and filter	$(N = 0.665\mu)$
				system for peak	
				response at 0.665μ .	
				Temperatures measured	
				with thermocouples.	



NORMAL SPECTRAL EMITTANCE OF ALUMINUM OXIDE

NORMAL SPECTRAL EMITTANCE OF ALUMINUM OXIDE -- REFERENCE INFORMATION

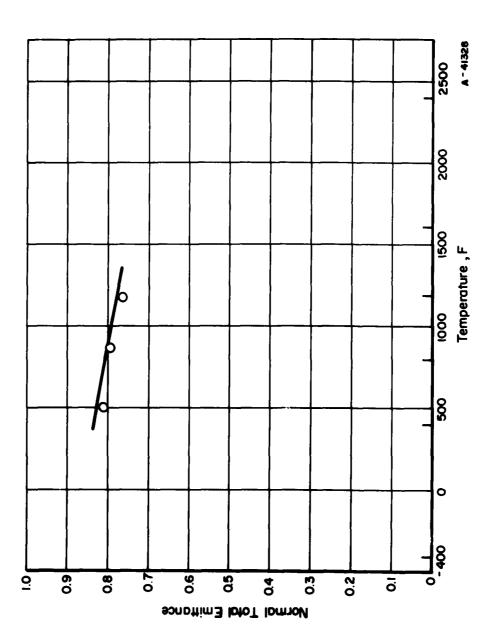
Reference	Investigator	Symbo1	Composition and Surface Condition	Test Method	Remarks
ო	Blau, Marsh, Martin, Jacobse, and		Aluminum oxide	Normal spectral emittance.	Measured in air.
	Chaffee		Diamond wheel finish as supplied by	of cylindrical Globar (SiC) heater.	CULVES.
			manufacturer	Comparison blackbody hole	(Curves are
			TWA No. 2 (Norton A 402) 98.56% Al ₂ 0 ₃	Temperatures measured with thermocouples. Monochromator and thermo-	the 1112 F points only.)
		0	Measured at 1112 F	couple detector.	
		×	Measured at 1922 F		
			Coors AD85 85% A1 ₂ O ₃		
		0	Measured at 1112 F		
		2	Measured at 1886 F		
			Coors AD99 99% A1 ₂ O ₃		
		٥	Measured at 1112 F		
		•	Measured at 1886 F		



SPECTRAL REFLECTANCE OF ALUMINUM OXIDE

SPECTRAL REFLECTANCE OF ALUMINUM OXIDE -- REFERENCE INFORMATION

Reference	Investigator	Symbo1	Composition and Surface Condition	Test Method	Remarks
7	Olson and Morris		Aluminum oxide Norton RA4213 and LA603 Surface condition not given	Spectral reflectance. Incident radiation 9 degrees from normal to specimen surface. Integrating sphere reflectometer. Monochromator and lead sulphide detector. Normal (9 degrees) illumination diffuse reflection.	Measured in air at room temperature. Data taken from curves.

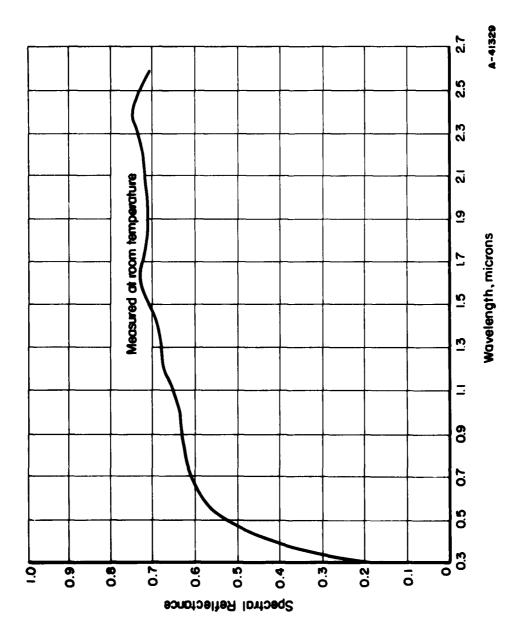


NORMAL TOTAL EMITTANCE OF BERYLLIUM OXIDE

NORMA: TOTAL EMITTANCE OF BERYLLIUM OXIDE -- REFERENCE INFORMATION

2 Olson and Morris (Sympot	Composition and Surface Condition	Test Method	Remarks
	0	Beryllium oxide	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Thermistor detector. Temperatures measured	Measured in air. Data taken from curves.

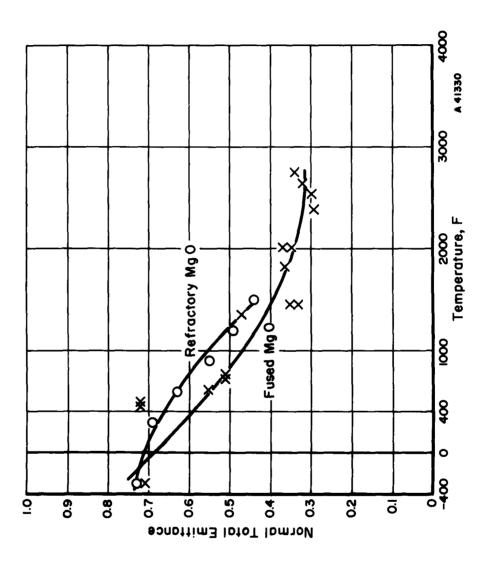
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SPECTRAL REFLECTANCE OF BERYLLIUM OXIDE

SPECTRAL REFLECTANCE OF BERYLLIUM OXIDE-REFERENCE INFORMATION

Dogos	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
anieratau .	יייי פאריאפיייי				
7	Retz. Olson. Schurin.		Beryllium oxide	Spectral reflectance.	Measured in air at
	and Morris		Purity not given	Incident radiation 9	room temperature.
•			As received condition	degrees from normal	Data taken from
				to specimen surface.	curves.
				Integrating sphere	
				reflectrometer.	
A				Monochromator, and lead	
L				sulphide detector.	
				Normal (9 degrees)	
				illumination and diffuse	
N				reflection.	
•					

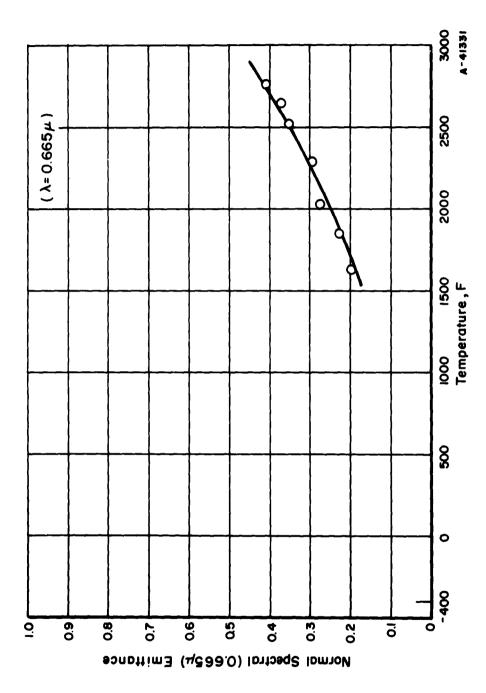


NORMAL TOTAL EMITTANCE OF MAGNESIUM OXIDE

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NORMAL TOTAL EMITTANCE OF MAGNESIUM OXIDE -- REFERENCE INFORMATION

Reference	Investigator	Symbo1	Composition and Surface Condition	Test Method	Remarks
~	Olson and Morris	×	Fused magnesium oxide obtained from the National Bureau of Standards. Surface condition not given	Normal total emittance. Furnace-heated specimen. Thermistor detector. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curve.
ω	Olson and Morris	0	Refractory magnesium oxide Composition and surface condition not given	(Same as above.)	(Same as above.)

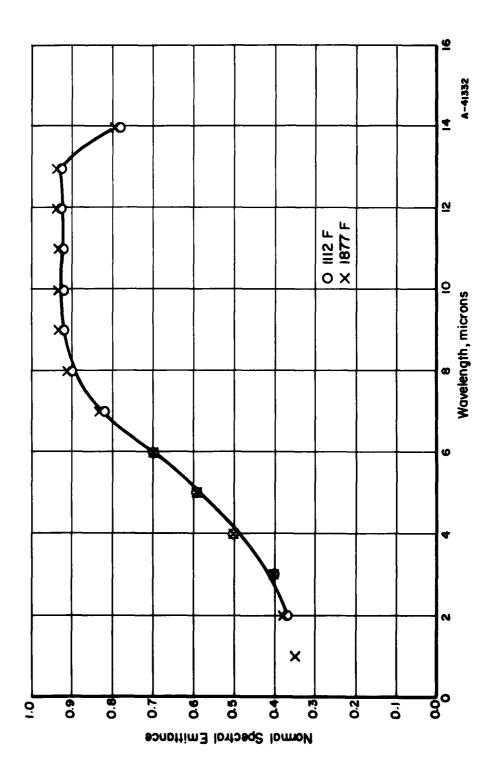


NORMAL SPECTRAL EMITTANCE OF MAGNESIUM OXIDE

NORMAL SPECTRAL EMITTANCE OF MAGNESIUM OXIDE-REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
8	Olson and Morris	0	Fused magnesium oxide obtained from National Bureau of Standards. Surface condition not given	Normal spectral emittance. Furnace-heated specimen. Comparison blackbody. Commercial detector and filter system for peak response at 0.665 μ . Temperatures measured with thermocouples.	Measured in air. Data taken from curves. $(\lambda = 0.665 \mu)$

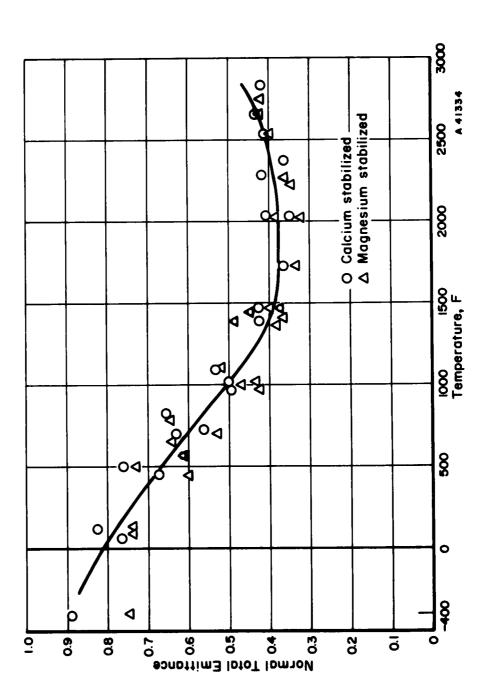
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NORMAL SPECTRAL EMITTANCE OF MAGNESIUM OXIDE

NORMAL SPECTRAL EMITTANCE OF MAGNESIUM OXIDE--REFERENCE INFORMATION

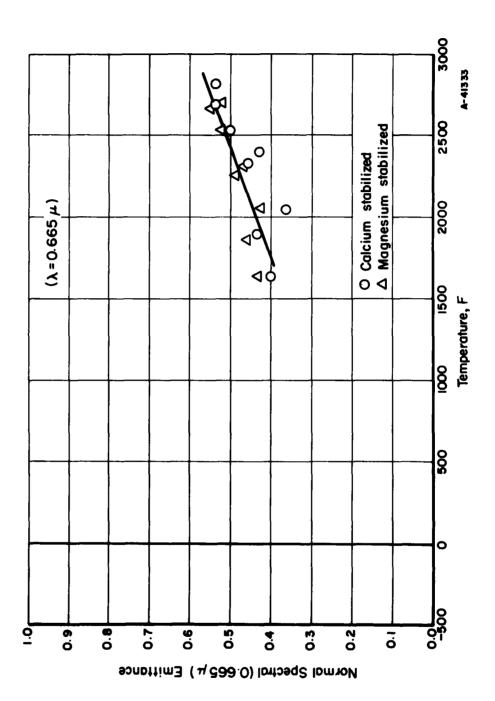
oo t	Reference	Investigator	Symbo1	Composition and Surface Condition	Test Method	Remarks
Norton RM4473 Purity: 97% MgO, 1.3-1.5% CaO Surface condition not given Measured at 1112 F Measured at 1877 F	ო	Blau, Marsh, Martin,		Magnesia (MgO)	Normal spectral emittance.	Measured in air.
Purity: 97% MgO, 1.3-1.5% CaO (Surface condition not given Measured at 1112 F Measured at 1877 F		Jasperse and		Norton RM4473	Specimen mounted in wall	Data taken from
oct .		Chaffee		Purity: 97% MgO,	of cylindrical Globar	curves.
oct P				1.3-1.5% CaO	(SiC) heater.	
not M					Comparison blackbody hole	(Curve drawn
M H				Surface condition not	in heater wall.	through 1112 F
H				given	Monochromator and	points only.)
			0	Measured at 1112 F	thermocouple detector. Temperatures measured	
			×	Measured at 1877 F	with thermocouples.	



NORMAL TOTAL EMITTANCE OF ZIRCONIUM OXIDE

NORMAL TOTAL EMITTANCE OF ZIRCONIUM OXIDE -- REFERENCE INFORMATION

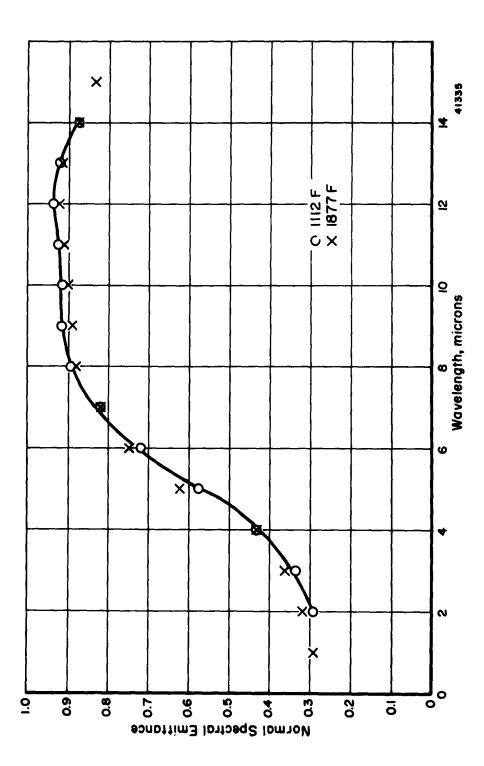
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
8	Olson and Morris	0 4	Zirconium oxide Galcium stabilized Magnesium stabilized	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.



NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM OXIDE

NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM OXIDE -- REFERENCE INFORMATION

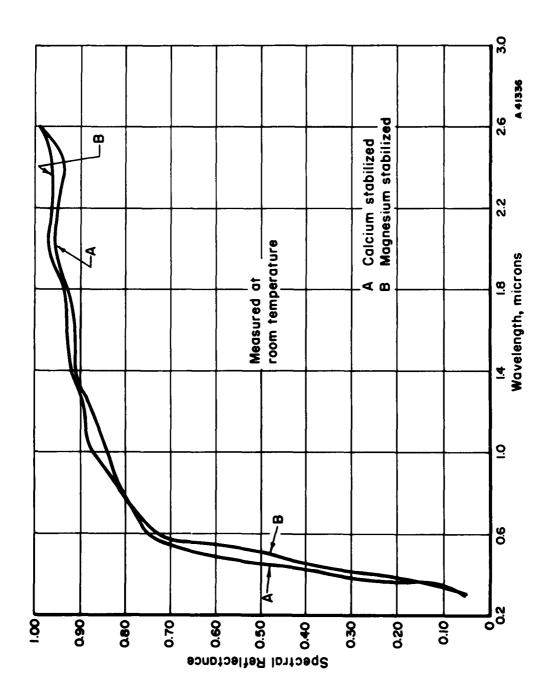
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
8	Olson and Morris	0 4	Zirconium oxide Calcium stabilized Magnesium stabilized	Normal spectral emittance. Furnace-heated specimen. Comparison blackbody. Commercial detector and filter system for peak response at 0.665/w. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. (>= 0.665 μ)



NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM OXIDE

NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM OXIDE.-REFERENCE INFORMATION

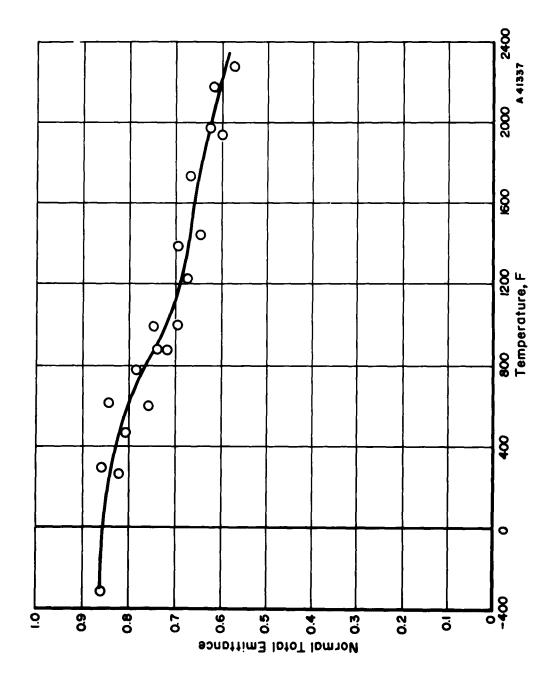
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
en	Blau, Marsh, Martin, Jasperse, and		Zirconia (ZrO ₂) Norton RZ 5601	Normal spectral emittance. Specimen mounted in wall of cylindrical Globar	Measured in air. Data taken from curves.
. 0 -			Purity: 92% ZrO2, 4.5% CaO	(SiC) heater. Comparison blackbody hole	(Curves drawn
			surface condition not given	Monochromator and	points only.)
•		0	Measured at 1112 F	thermocouple detector. Temperatures measured	
		×	Measured at 1877 F	with thermocouples.	



SPECTRAL REFLECTANCE OF ZIRCONIUM OXIDE

SPECTRAL REFLECTANCE OF ZIRCONIUM OXIDE -- REFERENCE INFORMATION

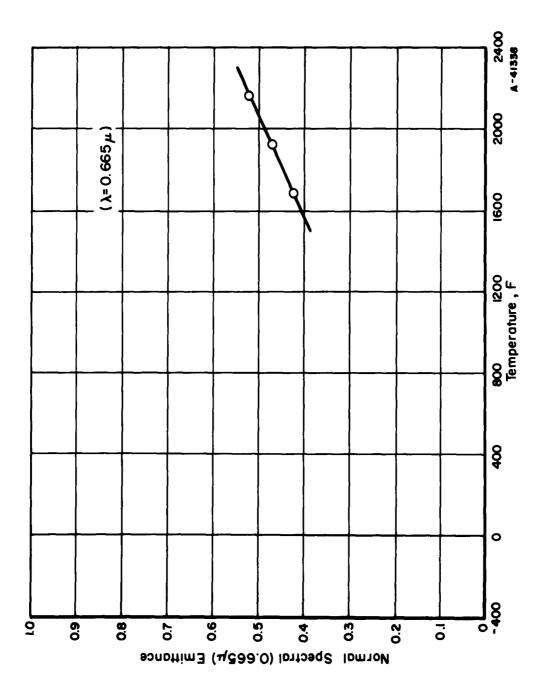
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
a	Olson and Morris		Zirconium oxide Galcium stabilized and magnesium stabilized Purity and surface condition not given	Spectral reflectance. Incident radiation 9 degrees from normal to specimen surface. Integrating sphere reflectometer. Monochromator and lead sulphide detector. Normal (9 degrees) illumination. Diffuse reflection.	Measured in air at room temper- ature. Data taken from curves.



NORMAL TOTAL EMITTANCE OF PYROCERAM 9606

NORMAL TOTAL EMITTANCE OF PYROCERAM 9606--REFERENCE INFORMATION:

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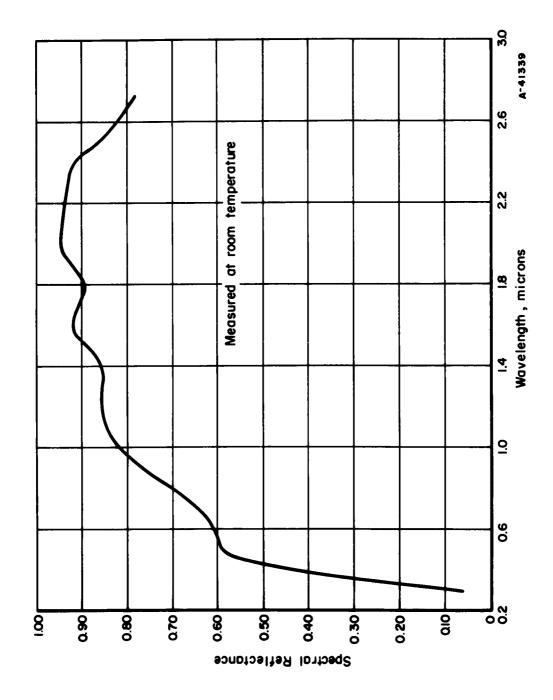


NORMAL SPECTRAL EMITTANCE OF PYROCERAM 9606

NORMAL SPECTRAL EMITTANCE OF PYROCERAM 9606--REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
8	Olson and Morris	0	Pyroceram 9606 Surface condition not given	Normal spectral emittance. Furnace-heated specimens. Comparison blackbody. Commercial detector and filter system for peak response at 0.665 \$\mu\$. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. $(\lambda = 0.665\mu)$

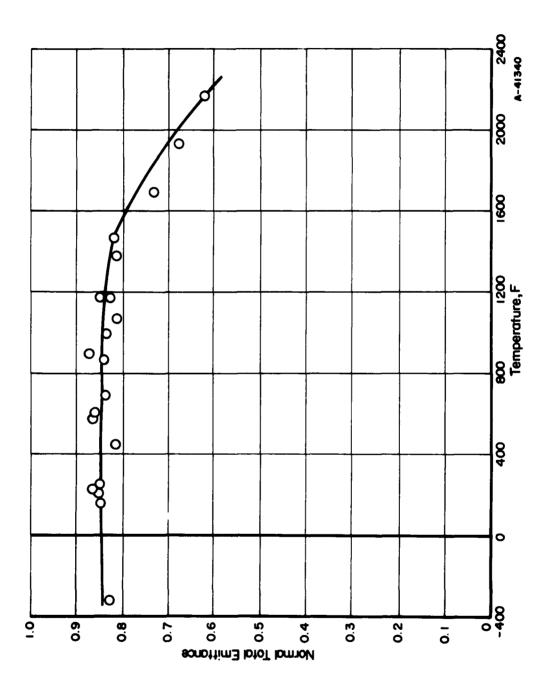
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SPECTRAL REFLECTANCE OF PYROCERAM 9606

SPECTRAL REFLECTANCE OF PYROCERAM 9606--REFERENCE INFORMATION

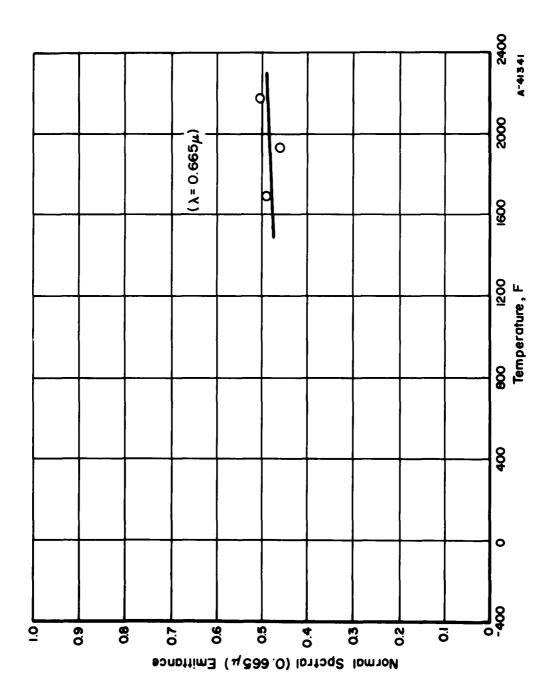
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
~	Olson and Morris		Pyroceram 9606 Surface condition not given	Spectral reflectance. Incident radiation 9 degrees from normal to specimen surface. Integrating sphere re- flectometer. Monochromator and lead sulphide detector. Normal (9 degrees) illumination. Diffuse reflection.	Measured in air at room temperature. Data taken from curves.



NORMAL TOTAL EMITTANCE OF PYROCERAM 9608

NORMAL TOTAL EMITTANCE OF PYROCERAM 9608--REFERENCE INFORMATION

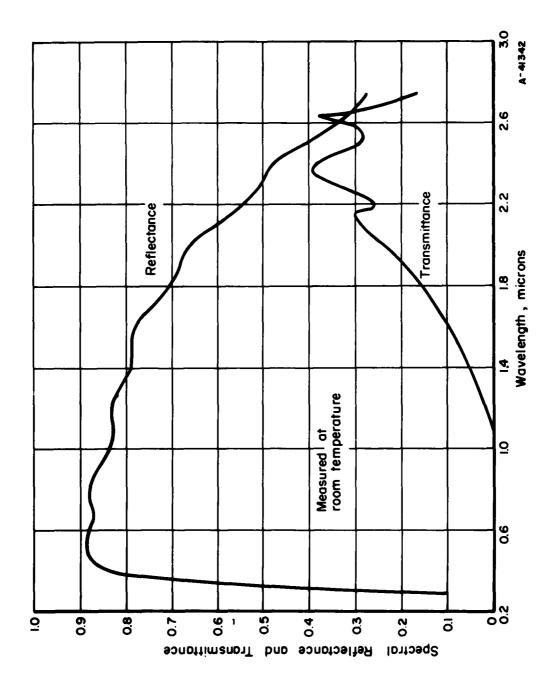
Reference	Reference Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
7	Olson and Morris	0	Pyroceram 9608 Surface condition not given	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curve.



NORMAL SPECTRAL EMITTANCE OF PYROCERAM 9608

NORMAL SPECTRAL EMITTANCE OF PYROCERAM 9608--REFERENCE INFORMATION

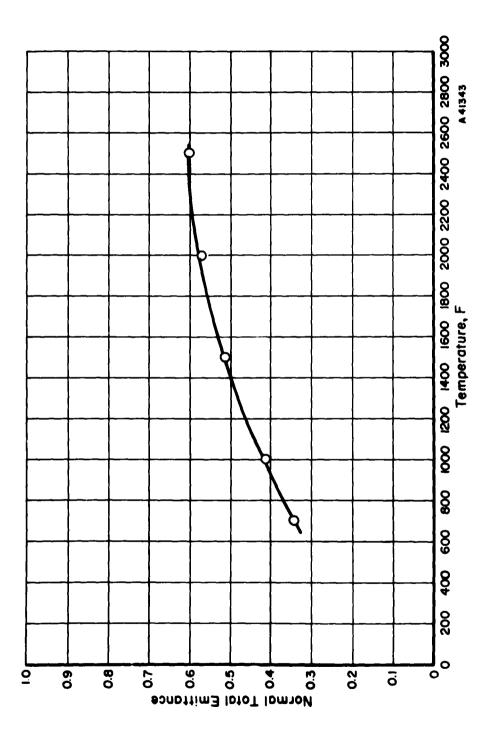
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
0	Olson and Morris	0	Pyroceram 9608 Surface condition not given	Normal spectral emittance. Furnace-heated specimen. Comparison blackbody. Commercial detector and filter system for peak response at 0.665 \$\mu\$. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. (λ= 0.665μ)



SPECTRAL REFLECTANCE AND TRANSMITTANCE OF PYROCERAM 9608

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SPECTRAL REFLECTANCE AND TRANSMITTAI
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Remarks	Ince. Measured in air at room temperature. In a bata taken from care. I lead I lead
Test Method	Spectral reflectance. Incident radiation 9 degrees from normal to specimen surface. Integrating sphere reflectometer. Monochromator and lead sulphide detector. Normal (9 degrees) illumination. Diffuse reflection. Spectral Transmittance. Normal specimen position filled by MgCO ₃ or MgO block. Specimen placed in entrance beam to sphere. Diffuse transmission.
Composition and Surface Condition	Pyroceram 9608 Surfaces reasonably flat and parallel
Symbo1	
Investigator	Olson and Morris
r Reference	C E MEMORIAL INSTITUTE

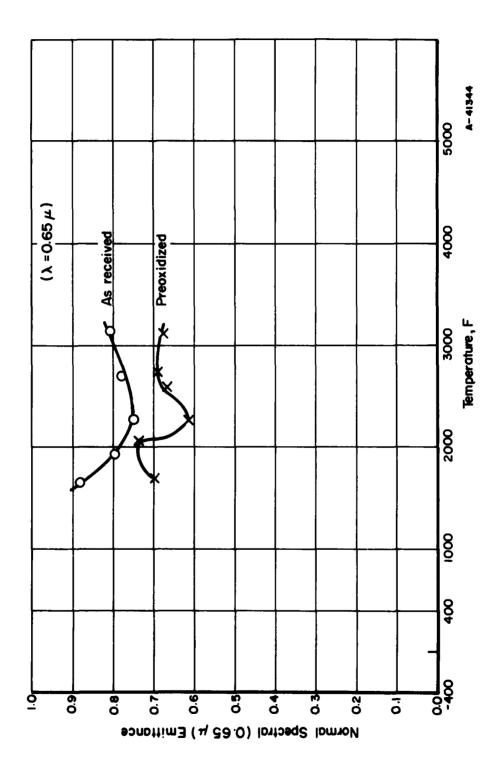


NORMAL TOTAL EMITTANCE OF MOLYBDENUM DISILICIDE

NORMAL TOTAL EMITTANCE OF MOLYBDENUM DISILICIDE--REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks	
-	Anthony and Pearl	0	As received	Normal total emittance. Induction-heated specimen. Thermopile detector. Comparison blackbody. Temperatures measured with thermocouples and optical pyrometer.	Measured in continuous purge of helium gas.	-101

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NORMAL SPECTRAL EMITTANCE OF MOLYBDENUM DISILICIDE

NORMAL SPECTRAL EMITTANCE OF MOLYBDENUM DISILICIDE-REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
4	Blau, Chaffee, Jasperse, and Martin	ο×	Molybdenum disilicide Surface clean and smooth Preoxidized (Lower emittance for the preoxidized surface attributed to SiO ₂ surface layer)	Normal spectral emittance. Induction-heated specimen. Blackbody hole drilled in specimen surface. Temperatures measured with micro-optical pyrometer.	Measured in 90% argon – 10% hydrogen atmosphere. Data taken from curves.

TOTAL SOLAR ABSORPTANCES AT SEA LEVEL AND ABOVE THE ATMOSPHERE

	Finish	Above Atmosphere	Sea Level
Graphite-National GBE	(F)	0.850	0.863
Graphite-National GBE	(B)	0.869	0.877
Graphite-National GBH	(M)	0,881	0.887
Graphite-National GBH	(R)	0.885	0.891
Graphite-Speer 3474D	(M)	0.853	0.858
Graphite-Speer 3474D	(R)	0.866	0.871
Graphite-Speer 7087	(M)	806.0	0.911
Graphite-Speer 7087	(R)	0.916	0.918
Beryllium Oxide (Refractory)	(R)	0.421	0.405
Magnesium Oxide (Refractory)	(R)	0.168	0.141

TOTAL SOLAR ABSORPTANCE OF BERYLLIUM OXIDE, MAGNESIUM OXIDE AND THREE GRAPHITES -- REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
7	Betz, Olson, Schurin, and Morris		Surface finishes: B* back	Solar absorptance calculated by method of truncated weighted	Calculated. Data obtained from table.
			F* front M fine milling	ordinate integration using spectral re-	
			machine cut R as received from supplier.	curves and solar energy distribution curves	
				to 2.4 microns. Above atmosphere values corrected for 3 per cent of energy lying outside these limits.	
			* back and front surfaces arbitrarily assigned to graphite sample. Sides appeared		

REFERENCES

- (1) Anthony, F. M. and Pearl, Harry A., "Investigations of Feasibility of Utilizing Available Heat Resistant Materials for Hypersonic Leading Edge Applications" (Vol. III Screening Test Results and Selection of Materials), WADC TR 59-744 (July, 1960).
- (2) Olson, O. H. and Morris, J. C., "Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials", Part III Techniques for Measurement, WADC TR 56-222, ASTIA AD 239302 (April, 1960).
- (3) Blau, H. H., Jr., Marsh, J. B., Martin, W. S., Jasperse, J. R. and Chaffee, E., "Infrared Spectral Emittance Properties of Solid Materials", AFCRL-TR-60-416, ASTIA AD 248276 (October, 1960).
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LIST OF DMIC MEMORANDA ISSUED DEFENSE METALS INFORMATION CENTER Battelle Memorial Institute Columbus 1, Ohio

Copies of the technical memoranda listed below may be obtained from DMIC at no cost by Government agencies and by Government contractors, subcontractors, and their suppliers. Others may obtain copies from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

A list of DMIC Memoranda 1-117 may be obtained from DMIC, or see previously issued memoranda.

DMIC Memorandum	
Number	Title
118	Review of Recent Developments in the Metallurgy of High-Strength Steels, July 21, 1961, (AD 259986 \$0.50)
119	The Emittance of Iron, Nickel, Cobalt and Their Alloys, July 25, 1961, (AD 261336 \$2.25)
120	Review of Recent Developments on Oxidation-Resistant Coatings for Refractory Metals, July 31, 1961, (AD 261293 \$0.50)
121	Fabricating and Machining Practices for the All-Beta Titanium Alloy, August 3, 1961, (AD 262496 \$0.50)
122	Review of Recent Developments in the Technology of Nickel-Base and Cobalt-Base Alloys, August 4, 1961, (AD 261292 \$0.50)
123	Review of Recent Developments in the Technology of Beryllium, August 18, 1961, (AD 262497 \$0.50)
124	Investigation of Delayed-Cracking Phenomenon in Hydrogenated Unalloyed Titanium, August 30, 1961
125	Review of Recent Developments in Metals Joining, September 1, 1961, (AD 262905 \$0.50)
126	A Review of Recent Developments in Titanium and Titanium Alloy Technology, September 15, 1961
127	Review of Recent Developments in the Technology of Tungsten, September 22, 1961
128	Review of Recent Developments in the Evaluation of Special Metal Properties, September 27, 1961
129	Review of Recent Developments in the Technology of Molybdenum and Molybdenum- Base Alloys, October 6, 1961
130	Review of Recent Developments in the Technology of Columbium and Tantalum, October 10, 1961
131	Review of Recent Developments in the Technology of High-Strength Stainless Steels, October 13, 1961
132	Review of Recent Developments in the Metallurgy of High-Strength Steels, October 20, 1961
133	Titanium in Aerospace Applications, October 24, 1961
134	Machining of Superalloys and Refractory Metals, October 27, 1961
135	Review of Recent Developments in the Technology of Nickel-Base and Cobalt-Base Alloys, October 31, 1961
136	Fabrication of Tungsten for Solid-Propellant Rocket Nozzles, November 2, 1961
137	Review of Recent Developments on Oxidation-Resistant Coatings for Refractory Metals, November 8, 1961
138	Review of Recent Developments in the Technology of Beryllium, November 16, 1961
139	Review of Recent Developments in the Technology of Tungsten, November 24, 1961
140	Review of Recent Developments in Metals Joining, December 6, 1961
141	The Emittance of Chromium, Columbium, Molybdenum, Tantalum, and Tungsten, December 10, 1961

LIST OF DMIC MEMORANDA ISSUED (Continued)

DMIC Memorandum Number	Title
142	Effects of Moderately High Strain Rates on the Tensile Properties of Metals, December 18, 1961
143	Notes on the Forging of Refractory Metals, December 21, 1961
144	Review of Recent Developments in Titanium Alloy Technology, December 29, 1961
145	The Use of Nickel-Base Alloys in the Rotating Parts of Gas Turbines for Aerospace Applications, January 11, 1962
146	Magnesium-Lithium Alloys - A Review of Current Developments, February 6, 1962
147	An Evaluation of Materials for Rocket-Motor Cases Based on Minimum Weight Concepts, March 8, 1962